TV Columbae in outburst: a mass transfer event?

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ABSTRACT

We have observed a 2-mag outburst of TV Col, the fourth to be recorded. We find that the line emission was greatly increased during the outburst, with the extra flux coming primarily from the impact region of the accretion stream with the disc. We suggest that the outburst was caused by increased mass transfer from the secondary. The 5.2-h modulation, which probably arises from a precessing accretion disc, changed phase during the outburst. We discuss the relation of outbursts in intermediate polars to those in dwarf novae.

Key words: accretion, accretion discs – stars: individual: TV Col – stars: magnetic fields – novae, cataclysmic variables.

1 INTRODUCTION

The cataclysmic variable TV Col exhibits a varied range of behaviours. First, it is an intermediate polar, containing a magnetic white dwarf which emits X-rays pulsed at the 32-min spin period (Schrijver et al. 1985). Secondly, in addition to the 5.5-h orbital cycle it shows photometric modulations at periods of 5.2 h and 4 d, the latter being the beat of the two 5-h cycles. Although no firm model has been established, the extra periods may be caused by a precessing accretion disc (e.g. Barrett, O'Donoghue & Warner 1988). Lastly, of primary interest here, it shows outbursts similar to those of the dwarf novae. The outbursts are short, rising and declining in hours, and have an amplitude of 2 mag. The first recorded outburst occurred in 1982 November and was observed by optical photometry and with IUE (Szkody & Mateo 1984). Two more outbursts were seen in 1987 November/December, separated by 8 d; Schwarz et al. (1988) obtained photometry of both outbursts and optical spectroscopy of the second. In this paper we report optical photometry and spectroscopy of an outburst in 1991 December, and discuss whether it was due to an instability in the secondary star or in the accretion disc.

2 PHOTOMETRY

We observed TV Col with the SAAO 0.75-m telescope and the UCT photometer over the interval 1991 December 3–14, making 10-s integrations with an unfiltered S-11 tube. To minimize errors due to guiding and episodes of bad seeing we used a wide (34 arcsec) aperture, including both TV Col and its close companion. We then subtracted the contribution of the companion, after determining it with a smaller aperture at a time of good seeing. We also made routine observations of the sky and a comparison star.

The reduced photometry is presented in Fig. 1. On 1991 December 9, TV Col went into outburst (these data are shown expanded in Fig. 2). On that night the observation began when TV Col was approaching a peak intensity of 2 mag brighter than normal. From the peak the star declined steeply at first (by 0.6 mag in 40 min) and then more slowly (by 0.6 mag in 5 h). On the following night TV Col averaged 0.5 mag brighter than the pre-outburst level, on the next night it was 0.2 mag brighter, and for the remainder of the observing run it was 0.1 mag brighter.

2.1 The 4-d and 5.2-h periods

The photometry (Fig. 1) shows no modulation at the 4-d period, with an upper limit of 0.1 mag full amplitude. This is in contrast to previous observations, where a modulation with an amplitude of 0.35 mag is prominent (e.g. Motech 1981; Barrett et al. 1988). A 5.2-h modulation, though, is obvious in Fig. 1. We show in Fig. 3 the Fourier transform of the data (after removing those from the night of outburst) plotted for comparison with the transform of the data obtained by Barrett et al. (1988) – this has the longest baseline and therefore the best-determined 5.2-h period of the published data sets. The transform indicates that the modulation in our data has a significantly shorter period. To investigate, we have judged by eye the times of 5.2-h maximum on the individual nights and compared them with the ephemeris given by Hellier (1993). Since timings of the 5.2-h maximum may be distorted by the orbital modulation, we first subtracted a best-fitting 5.5-h...
Figure 1. White light photometry over the interval 1991 December 3–14, showing the outburst. The 5.2-h modulation is also apparent on each night.

Figure 2. The photometry of the night of outburst, showing the times of our spectroscopic observations at lower resolution (arrows) and higher resolution (dashed line). We also mark the time of eclipse according to the ephemeris of Hellier (1993).

Figure 3. The Fourier transform for periods near 5.2 h of the photometry shown in Fig. 1, after removing the data from the night of outburst. For comparison we also show (lighter line) the transform of the data obtained by Barrett et al. (1988), revealing a significant difference in the frequency of the 5.2-h modulation.

Figure 4. The residuals to the timings of the 5.2-h cycle from the individual nights, plotted against the ephemeris of Hellier (1993); a horizontal line thus indicates a period unchanged from previous data. The diagram suggests that the phase is changed by the outburst.

The residuals (plotted in Fig. 4) show a general trend to smaller values over the observing period (as expected if the true period is shorter). However, there is an alternative interpretation of this diagram. It is possible that the period has not changed, but that the modulation changes phase during the outburst. The best-fitting lines for the two interpretations are drawn in Fig. 4. The model with a phase-change in outburst has the smaller $\chi^2$, 6.6 compared with 12.8, and so is strongly preferred (the values are directly comparable since in each case two parameters are fitted to the data, a phase and a period in one case, and two phases in the other; however, the absolute values have little meaning since the error bars were determined by eye). There is a further indication that the 5.2-h modulation was changed by the outburst: as can be seen from Fig. 1, the modulation amplitude is greater afterwards (semi-amplitude of $20 \pm 2$ per cent) than before ($12 \pm 2$ per cent). Hence we conclude that the
Table 1. 5.2-h maximum timings.

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<th>JD&lt;sub&gt;⊙&lt;/sub&gt;</th>
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5.2-h modulation had a phase of ~0.52 before the outburst, which changed to ~0.11 after the outburst.

3 SPECTROSCOPY

On the night of outburst we obtained spectroscopy of TV Col using the SAAO 1.9-m telescope, Image Tube Spectrograph and the Reticon Photon Counting System. Near the peak of the outburst, two 10-min exposures were made with a 600 line mm<sup>-1</sup> grating, giving 3-Å resolution over a useful range of 3500–5200 Å. We then changed to a 1200 line mm<sup>-1</sup> grating, giving 1.3-Å resolution over a range of 4200–5100 Å, and obtained 72 exposures of 200 s each. The data from the two gratings combine to span almost exactly one orbital cycle; the times are indicated in Fig. 2.

The sum of the two lower resolution spectra is shown in Fig. 5. It contains emission lines of the Balmer series, He<sub>1</sub> λλ4027, 4388, 4471, 4713, 4920 and the higher excitation lines He<sub>2</sub> λλ4541, 4686 and C<sub>III</sub>/N<sub>III</sub> 4640. The most striking difference in comparison with quiescent spectra of TV Col (e.g. Hellier 1993) is the relative enhancement of the higher excitation lines. The time variations of the equivalent widths of the He<sub>2</sub> λ4686 and H<sub>α</sub> lines are shown in Fig. 6. Initially the equivalent widths of all lines are greatly enhanced, but by the end of the night they have subsided back to quiescent levels.

We have allocated the spectra (both lower and higher resolution) into 20 phase bins over the one orbital cycle observed. The coverage begins at phase 0.2 after eclipse and continues for one cycle (note that the third bin is empty owing to the grating change). The time sequences of profiles of the He<sub>2</sub> λ4686 and H<sub>α</sub> lines are shown in Figs 7 and 8 and displayed as a grey-scale in Fig. 9 (opposite p. 770). Note that each bin of the grey-scale is normalized to the continuum, so that the profiles are displayed as quasi-equivalent widths.

For comparison, Fig. 9 also shows phase-resolved profiles in quiescence (taken from Hellier 1993). The quiescent He<sub>2</sub> λ4686 line is dominated by an S-wave component arising from the impact of the mass transfer stream with the edge of the accretion disc. It is phas with maximum redshift at phase 0.14 ± 0.06 and is markedly brighter near phases 0.2 and 0.8. The quiescent H<sub>α</sub> line shows the same S-wave superimposed on a broader disc component which varies with the orbital velocity of the white dwarf (maximum redshift near phase 0.75). Near phase 0.9 the emission is reduced by absorption in the line centre (see Hellier 1993 for an analysis of the quiescent spectra).

The outburst profiles of He<sub>2</sub> λ4686 are again dominated by the S-wave; its phasing and velocity are compatible with the quiescent S-wave, while it again shows brightenings near phases 0.2 and 0.8. Clearly, though, the S-wave is diminishing rapidly through the night. At the outburst peak the flux in the S-wave is enhanced by a factor of ~30 relative to quiescence, but by the end of the night it is less than twice the quiescent level. The outburst profiles of He<sub>2</sub> λ4686 possess a broader base which is not apparent in quiescence – this is probably disc emission. In outburst the H<sub>α</sub> line also shows the S-wave to be greatly enhanced initially but diminishing with time. The disc emission is still present and there is again evidence for reduced emission in the line centre near phase 0.8, although the S-wave is sufficient to fill it in when it crosses the line centre (phase 0.9–1.0). There is some slight evidence for a reduction in continuum flux and in equivalent width of the He<sub>2</sub> λ4686 line at eclipse (Figs 2 and 6).

4 DISCUSSION

The four reported outbursts of TV Col (Szkody & Mateo 1984; Schwarz et al. 1988; this paper) are all similar in amplitude (2
mag) and duration (hours). Additionally, where observations have been made, the outbursts have been accompanied by large increases in emission-line flux, particularly in the higher ionization lines. These similarities suggest that TV Col's outbursts are a homogeneous phenomenon.

Further, TV Col's outbursts are similar to those of two other intermediate polars, EX Hya and V1223 Sgr. The outbursts of EX Hya have an amplitude of ~4 mag, last for ~2 d and show increases in emission-line equivalent width (e.g. Helliger et al. 1989). V1223 Sgr has shown an outburst lasting for <1 d with a >1-mag amplitude and, again, an increase in emission-line equivalent width (van Amerongen & van Paradijs 1989). [The other intermediate polar to show outbursts, GK Per, behaves very differently, with outbursts lasting for months; it is also atypical in having a very long (2-d) orbital period, e.g. Kim, Wheeler & Mineshige (1992).] The behaviour of TV Col, EX Hya and V1223 Sgr contrasts with that of non-magnetic dwarf novae, where the emission lines are greatly reduced or change to absorption as the system rises. There are exceptions such as IP Peg which, during outburst, has an emission-line spectrum similar to that of TV Col (Marsh & Horne 1990). Although the difference in behaviour may be related to the inclinations of the binaries (both EX Hya and IP Peg show eclipses of the white dwarf), the majority of high-inclination dwarf novae do not show emission-line spectra in outburst, suggesting that the three intermediate polars are systematically different.

Another systematic difference is the shorter duration of the outbursts in intermediate polars: EX Hya's 2-d outbursts are at the lower end of the typical range for dwarf novae, while the ~12-h outbursts of TV Col and V1223 Sgr are shorter than seen in any non-magnetic systems (in addition, the 2-mag amplitude of these outbursts is at the lower end of the typical amplitude distribution). In TV Col the UV flux rose at the same time as the optical in the outburst seen by Szkody & Mateo (1984), while in some dwarf novae the UV can be delayed by up to a day. Also, the outbursts of a particular magnetic system are all similar (although admittedly few have been observed), and the duality common in non-magnetic systems (long/short outbursts or normal/super outbursts) has not been seen.

A major difference between the intermediate polars and typical dwarf novae is seen in the S-waves, which are caused by the accretion stream as it interacts with the disc. In general in dwarf novae the flux from the bright spot is comparable in quiescence and outburst, so that, although the S-wave and/or orbital hump can be prominent in quiescence, they become less significant contributors to the flux in outburst. This is a major argument supporting the proposal that dwarf nova outbursts are due to instabilities in the accretion disc rather than in the secondary star (e.g. Meyer-Hofmeister & Ritter 1993). In our observations of TV Col, however, the emission-line flux from the S-wave increases dramatically during the outburst. At the peak of the outburst the H\(\text{He}\,\lambda 4686\) S-wave flux is 30 times the quiescent level, compared to a continuum.
rise of a factor of 6. The S-wave declines rapidly after the outburst peak to only a factor of 2 greater than quiescence by the end of the night. The same behaviour is seen in the Balmer lines. During an outburst of EX Hya, Hellier et al. (1989) saw a high-velocity S-wave feature which is not present in quiescence. This might be produced if the accretion stream overflows the initial impact with the disc and continues on a ballistic trajectory to an impact near the magnetosphere.

4.1 A disc instability model?

The disc instability model has had considerable success in explaining dwarf nova outbursts (e.g. Meyer-Hofmeister & Ritter 1993; Livio 1993). Hence it may well apply to the intermediate polars also, with the systematic differences in these stars caused by the lack of an inner disc as a result of the strong magnetic field (see Szkody & Mateo 1984; Schwarz et al. 1988; van Amerongen & van Paradijs 1989). Angelini & Verbunt (1989) have calculated that this results in the shorter outbursts seen in the magnetic systems. The absence of an inner disc also reduces the UV delay. To explain the different emission-line behaviour one could invoke irradiation. Intermediate polars tend to accrete at the polar regions of the white dwarf, rather than at the equatorial regions, which would facilitate illumination of the disc. Further, a bloated inner disc might block irradiation in non-magnetic systems, but be absent in the intermediate polars. The bright S-wave seen in TV Col would also have to result from irradiation. However, if this is true it is unclear why it is not also seen in dwarf novae such as SS Cyg, U Gem and VW Hya, which are also X-ray/EUV emitters in outburst. Features due to irradiation of the secondary star are seen in dwarf nova outbursts (e.g. Marsh & Horne 1990), but bright S-waves from the stream are generally not seen. Further, there is no obvious explanation for the high-velocity S-wave seen in EX Hya only during outburst.

4.2 A secondary instability?

The alternative explanation for the bright S-wave in TV Col in outburst is a burst of mass transfer from the secondary star. Since the S-wave declines rapidly, the enhanced mass transfer would last for only a few hours. Similarly, the high-velocity S-wave seen in an outburst of EX Hya appears near the peak of the outburst only, and was not seen a day later during the decline (Hellier et al. 1989). Since this implies a short episode when the stream overflows the disc, it could also be explained by a burst of mass transfer. Reinsch & Beuermann (1990) obtained photometry early in the same outburst of EX Hya. They report that the narrow eclipse normally seen in quiescence, which is of the white dwarf and its environs, is replaced by a much broader feature, suggesting that the outer disc has become relatively much brighter. Further, they report that the eclipse is delayed by ~ 2 min relative to the quiescent (white dwarf) eclipse. This implies that the enhanced emission lies preferentially ahead of the line of stellar centres, which is consistent with an enhanced accretion stream.

Angelini & Verbunt (1989) calculate that outbursts of the observed length and without a UV delay can occur with a mass transfer burst on to a system lacking an inner disc. This would be particularly so if part of the accretion flows directly on to the magnetosphere, as suggested by the observations of EX Hya. To make a crude estimate of the mass transfer implied by this model, we assume that the mass transfer rate scales simply by the visual magnitude and that the rates in quiescence are those given by Patterson (1984), 10^{-9} M_\odot yr^{-1} for TV Col and 10^{-10} M_\odot yr^{-1} for EX Hya. The extra flux then implies a mass transfer burst of ~ 6 \times 10^{-12} M_\odot for TV Col and ~ 8 \times 10^{-13} M_\odot for EX Hya.

There is further evidence supporting a secondary instability. V1223 Sgr shows YY Scii behaviour, that is, it has low states when its magnitude drops from ~ 13 to ~16.8 (Garnavich & Szkody 1988). The usual explanation for such anti-dwarf-novae is that during their high states the mass transfer rate is sufficiently high that the discs lie on the hot side of the disc instability; then, in the minima, the accretion rate drops so that the disc cools below the instability or disappears altogether. However, the outburst of V1223 Sgr observed by van Amerongen & van Paradijs (1989) occurred when it was in a high state (i.e. already in outburst in the disc instability model), and hence a different mechanism is required. Similarly, it is interesting to note that the light curve of the intermediate polar AO Psc presented by Garnavich & Szkody shows both a low state and one point where it is ~ 1 mag brighter than its usual high state, suggesting that AO Psc might also be added to the list of magnetic dwarf novae.
Figure 9. The He II λ4686 and Hβ line profiles from the night of outburst, allocated into time bins of 1/20th of the orbital cycle and displayed as a grey-scale. The spectra start at orbital phase 0.2 and continue for one orbital cycle. The third bin is empty due to a grating change to higher resolution. For comparison we show the line profiles of quiescent data when folded on the orbital cycle, taken from Hellier (1993).
The 5.2-h modulation in TV Col's light curve changed phase and amplitude abruptly during the outburst (Section 2.1). The 5.2-h and 4-d modulations are probably caused by an eccentric precessing disc (e.g. Hellier 1993). It is highly probable that a burst of mass transfer would have a significant effect on a disc eccentricity. For instance, Whitehurst & King (1991) have proposed that the perturbation by the mass transfer stream plays a significant role in the growth and phasing of the disc eccentricity in SU UMa stars in superoutbursts.

To summarize, a case can be made that short bursts of mass transfer cause the outbursts of intermediate polars. We thus consider whether they occur more generally.

4.3 Relation to other systems

Although the disc instability model explains much of the non-magnetic dwarf nova phenomenology, there is evidence that mass transfer events occur in these stars also. For instance, eclipse mapping of the accretion disc during superoutbursts of Z Cha shows that the superhump light originates in an extended region around the rim of the disc (Warner & O'Donoghue 1988). However, one anomalous eclipse profile showed, instead, that the extra light was located at the bright spot (O'Donoghue 1990). This eclipse, which implies a bright spot 20 times more luminous than in quiescence, is the earliest eclipse of a superhump yet recorded in an outburst. This suggests that a short-lived mass transfer event may be an important factor early in a superoutburst. Also in Z Cha, Bateson (1991) lists 26 possible examples of short-lived flares, different from the normal outbursts but similar to those seen in the intermediate polars.

If mass transfer events are occurring in intermediate polars, this may be related to the larger X-ray flux in the magnetic systems irradiating the secondary and affecting the mass transfer rate (e.g. King 1989). Such irradiation-induced mass transfer has been proposed to explain the high and low states in AM Her stars, which also have a strong X-ray flux (King & Lasota 1984). Since superoutbursts in SU UMa stars appear to be triggered by normal (disc instability?) outbursts, the increased irradiation might cause increased mass transfer (cf. the anomalous eclipse) and hence a superoutburst (cf. Osaki 1985).

If this is correct, one might expect similar mass transfer events in AM Her stars (although the situations are not identical; for instance, direct illumination of the L point would occur in AM Hers but would be blocked by the accretion discs in intermediate polars). In the absence of a disc, the outburst duration is likely to be even shorter than in the intermediate polars. The enhanced mass transfer would probably result in large 'blobs' of material which burrow into the white dwarf surface and thermalize to emit predominantly in the EUV. Interestingly, such events may have been observed from RE1938–46 with EYU (Warren et al. 1993).

Finally, if we are correct in attributing intermediate polar outbursts to secondary instabilities, why don't they show disc instabilities? For a long-period system such as TV Col, this could simply result from a high mass transfer rate keeping the disc in a permanent outburst state. However (assuming that dwarf nova outbursts are disc instabilities), it is highly unusual for a system below the period gap, such as EX Hya, to have a stable disc. Possibly the high X-ray flux or the magnetic disruption of part of the disc suppresses the instability.

5 CONCLUSIONS

(1) Near the peak of a 2-mag outburst of TV Col, the emission-line flux arising from the impact of the mass transfer stream with the accretion disc was 30 times greater than in quiescence. We explain this with a burst of enhanced mass transfer from the secondary star. Such events may be occurring in several classes of cataclysmic variable.

(2) The outburst altered the amplitude and phase of the 5.2-h modulation (which most likely arises in a precessing accretion disc). More extensive observations of such phenomena would be difficult to obtain, but would yield valuable information about the interaction of the mass transfer stream with the disc.

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REFERENCES


NOTE ADDED IN PROOF
We refer the reader interested in TV Col to the forthcoming paper by Augusteijn et al. (1993), which discusses similar issues to those covered in this paper.
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